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Indian Standard

HYDRAULIC FLUID POWER — VALVES — DETERMINATION OF PRESSURE DIFFERENTIAL/FLOW CHARACTERISTICS

UDC 621·646·2-82 : 53·083·6

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BUREAU OF INDIAN STANDARDS
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Hydraulic Fluid Power Systems Sectional Committee, PE 15

NATIONAL FOREWORD

This Indian Standard which is identical with ISO 4411 : 1986 'Hydraulic fluid power — Valves — Determination of pressure differential/flow characteristics' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendations of the Hydraulic Fluid Power Systems Sectional Committee (PE 15) and approval of the Production Engineering Division Council.

The text of ISO standard has been approved as suitable for publication as Indian Standard without deviation. Certain conventions are however not identical with those used in the Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear, referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker in the International Standard while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to ISO 1219 'Fluid power systems and components — Graphic symbols'. The Indian Standard IS 7513 : 1974 'Graphical symbols for fluid power systems', which is technically equivalent with ISO 1219, is to be substituted in its place.

Indian Standard

HYDRAULIC FLUID POWER — VALVES — DETERMINATION OF PRESSURE DIFFERENTIAL/FLOW CHARACTERISTICS

0 Introduction

In hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure within an enclosed circuit. Hydraulic valves control the direction, pressure or flow rate of the fluid in the system.

When the fluid flows through a valve it encounters some resistance which results in a loss of pressure called "pressure differential"

This International Standard is intended to unify testing methods for hydraulic fluid power valves to enable the pressure differential/flow characteristics of different valves to be compared.

1 Scope and field of application

This International Standard specifies methods for determining, under steady-state conditions, the pressure differential caused by the flow through any given path in a hydraulic fluid power valve. Requirements for test installations, procedures and presentation of results are specified.

This International Standard may also be applied to other fluid power components where similar conditions apply.

Accuracy of measurement is divided into three classes (A, B and C) which are explained in annex A. Guidance as to the use of practical units for the presentation of results is given in annex C. Annex D provides a pre-test checklist of those items where agreement is recommended between the parties concerned.

2 Reference

ISO 1219, *Fluid power systems and components — Graphic symbols.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 nominal diameter of valve, D: The manufacturer's values for the nominal diameter of the valve.

3.2 flow rate, q_V: The volume rate of flow at the point of measurement, see 5.1.11.

3.3 valve-related fluid velocity, u: The mean velocity of the fluid based upon the flow rate q_V and the valve diameter D.

3.4 pipe-related fluid velocity, v: The mean velocity of the fluid based upon the flow rate q_V and the pipe internal diameter d.

3.5 Reynolds number, Re: A dimensionless quantity defined by the expressions

$$Re = \frac{uD}{\nu} \text{ (valve-related) and}$$

$$Re = \frac{vd}{\nu} \text{ (pipe-related)}$$

3.6 pressure differential, Δp: The pressure loss attributed to the valve (see 6.5).

3.7 loss coefficient, k: A coefficient used in non-dimensional presentation of valve loss. It is defined by the expression

$$k = \frac{2\Delta p}{\varrho u^2}$$

3.8 pipe length, l: The sum of the pipe lengths between the upstream and downstream pressure-tapping points.

3.9 friction factor, μ: A coefficient used in non-dimensional presentation of pipe loss, see annex B.

4 Symbols and units

4.1 The symbols and units used throughout this International Standard are as shown in table 1.

4.2 The graphical symbols used in figures 1 to 3 are in accordance with ISO 1219.

5 Test installations

5.1 Test circuits

5.1.1 A circuit suitable for testing valves as shown in figure 1 shall be used.

NOTE — Figure 1 illustrates a basic circuit which does not incorporate all the safety devices necessary to protect against damage in the event of component failure. It is important that those responsible for carrying out the test give due consideration to safeguarding both personnel and equipment.

5.1.2 A fluid supply with controllable flow shall be used.

5.1.3 A pressure-relief valve shall be installed in the supply line to protect the circuit from excess pressures.

5.1.4 To establish a steady flow pattern at the upstream pressure tapping, the length of pipe upstream of that tapping shall conform with the following requirements:

a) for class A measurement accuracy, a visibly straight, uniform bore pipe length of 50d shall be used;

b) for class B or C measurement accuracy, a visibly straight, uniform bore pipe length of at least 10d shall be used.

5.1.5 For all classes of accuracy of measurement, a visibly straight, uniform bore pipe length of 5d shall be used between the upstream pressure tapping and the valve.

5.1.6 To ensure adequate pressure recovery, a visibly straight, uniform bore pipe length of 10d shall be used between the valve and the downstream pressure tapping.

5.1.7 A visibly straight, uniform bore pipe length of 5d shall be used between the downstream pressure tapping and the temperature-measuring point.

Table 1 — Symbols and units

Reference clause	Quantity	Symbol	Dimension[1]	Unit[2]
3.1	Nominal diameter of valve	D	L	m
3.2	Volume flow rate	q_V	L^3T^{-1}	m^3/s
3.3	Fluid velocity — valve-related	u	LT^{-1}	m/s
3.4	Fluid velocity — pipe-related	v	LT^{-1}	m/s
3.5	Reynolds number	Re	pure number	
3.6	Pressure differential	Δp	$ML^{-1}T^{-2}$	Pa[3]
3.7	Coefficient — valve loss	k	pure number	
3.8	Pipe length	l	L	m
3.9	Friction factor — pipe	μ	pure number	
—	Inside diameter of pipe	d	L	m
—	Temperature	θ	Θ	K
—	Kinematic viscosity	ν	L^2T^{-1}	m^2/s
—	Mass density	ϱ	ML^{-3}	kg/m^3

1) M = mass; L = length; T ≐ time; Θ = temperature

2) The use of practical units for the presentation of results is described in annex C.

3) 1 Pa = 1 N/m^2

5.1.8 A visibly straight, uniform bore pipe length of 5*d* shall be used downstream of the temperature-measuring point.

5.1.9 Pipes and fittings consistent with the nominal diameter of the valve shall be used.

5.1.10 All pipes shall be mounted in the horizontal plane; if this is not possible, a correction factor shall be applied to the measured pressures.

5.1.11 A flowmeter shall be installed to measure the flow rate at a point downstream of the pipe length described in 5.1.8.

5.2 Pressure-tapping points

5.2.1 For class A measurement accuracy, static pressure-measuring connections shall be used which consist of a piezometer ring having

a) two equally spaced tappings, if the pipe inside diameter, *d*, is equal to or less than 6 mm;

b) three or more equally spaced tappings, if the pipe inside diameter, *d*, is greater than 6 mm.

The tappings and the measuring device shall be connected with one lead.

5.2.2 For classes B and C measurement accuracy, single pressure-tappings may be used.

5.2.3 The centreline of the tappings shall intersect the pipe centreline and be normal to it.

5.2.4 No tapping shall be installed on the lowest point of the pipe.

5.2.5 Pressure-tappings having identical diameters which are equal to or less than 0,1*d*, but not less than 1 mm nor greater than 6 mm, shall be used.

5.2.6 The length of a pressure-tapping hole shall not be less than twice its diameter.

5.2.7 The connecting lead to the pressure-measuring device shall have a cross-sectional area of not less than half the total area of the tapping holes.

5.3 Filtration

5.3.1 A filter shall be installed which provides a standard of filtration approved by the valve manufacturer.

5.3.2 The position and specific description of each filter used in the test circuit shall be stated.

6 Test procedures

6.1 Test fluid

6.1.1 A test fluid approved by the manufacturer of the valve shall be used when carrying out the tests. Information concerning the fluid shall be recorded.

6.1.2 For classes A and B measurement accuracy, the mass density, ϱ, and the kinematic viscosity, ν, from fluid samples taken from the test installation shall be measured immediately before the test.

6.1.3 For class C measurement accuracy, it is permissible to use density and viscosity data obtained from the fluid supplier.

6.1.4 The kinematic viscosity, ν, and the mass density of the fluid, ϱ, for the range of temperatures used in the test shall be stated.

6.2 Temperatures

6.2.1 When a dimensional presentation is required (see 6.6.3) and the test is to be carried out with one stated fluid at one temperature, the temperature shall be controlled during the test within the limits specified in table 2.

Table 2 — Permissible variation in indicated fluid temperature

Class of measurement accuracy (see annex A)	A	B	C
Variation in temperature indication, K	± 1,0	± 2,0	± 4,0

6.2.2 When a non-dimensional presentation is required (see 6.6.2), there is no requirement for the complete test to be carried out at one controlled temperature, but for each test condition the temperature is required to be stable within the limits specified in table 2.

6.2.3 The tests shall be carried out within the range of fluid temperatures recommended by the valve manufacturer for the intended application of the valve.

6.3 Steady-state conditions

6.3 1 All readings shall only be recorded after steady-state conditions have been reached.

6.3.2 When steady-state test conditions are reached for a specific test condition, only one set of readings of individual quantities shall be taken over concurrent common time periods. Each reading shall be recorded as the mean value of each quantity being measured.

6.4 Performance

The number of sets of readings to be taken and their distribution over the range shall be selected to give a representative indication of the performance of the valve over the full range of flow selected for the test.

6.5 Pressure differential

Calculate the valve pressure loss, Δp, by subtracting the pipe loss (see annex B) from the total measured loss.

For this purpose, the connecting fittings shall be considered as being part of the valve.

6.6 Presentation of the test results

6.6.1 General

All test measurements and the results of calculations therefrom shall be tabulated by the testing agency and preferably also presented graphically as described in 6.6.2, 6.6.3 and 6.6.4.

6.6.2 Non-dimensional presentation

6.6.2.1 For valves which have a fixed internal geometry, a non-dimensional graphical presentation as shown in figure 2[1] shall be used. The flow is represented by the valve-related Reynolds number (see 3.5) and the pressure differential by a loss coefficient k (see 3.7).

6.6.2.2 Calculate the values for Re and k (see 3.5 and 3.7), using known values of kinematic viscosity, ν, and mass density, ϱ, at each controlled temperature and plot k against Re on log-log scales.

NOTE — The results of a series of tests with different fluid kinematic viscosities and mass densities will produce one curve when the flow aperture dimensions of the valve are unaffected by changes in the rate of flow or pressure.

6.6.3 Dimensional presentation

When required for specific applications, the test results shall be presented dimensionally as a graph of pressure differential, Δp, against the flow rate, q_V. The kinematic viscosity and mass density at the controlled fluid temperature shall also be stated. An example is shown in figure 3[1].

NOTE — A dimensional presentation can be produced from the results of non-dimensional presentation by calculating the valve-related Reynolds numbers for given flow, finding the value of k from the k-Re curve and calculating the pressure differential by transposing the equation given in 3.7 as follows:

$$\Delta p = k \varrho \frac{u^2}{2}$$

6.6.4 Valves with variable internal geometry

Where valves have an internal geometry which is variable as a function of flow or pressure, the procedure for a non-dimensional presentation, as described in 6.2.2 and 6.6.2, will not result in one curve; a dimensional presentation, as described in 6.2.1 and 6.6.3, is therefore implied.

A typical example of curves for a spring-loaded non-return valve is given in figure 4[1]. When the valve is maintained in the fully open condition, a value for the loss coefficient, k, can be determined.

7 Identification statement (Reference to this International Standard)

Use the following statement in test reports, catalogues and sales literature when electing to comply with this International Standard:

"Test for the determination of pressure differential flow characteristics conforms to ISO 4411, *Hydraulic fluid power — Valves — Determination of pressure differential/flow characteristics*".

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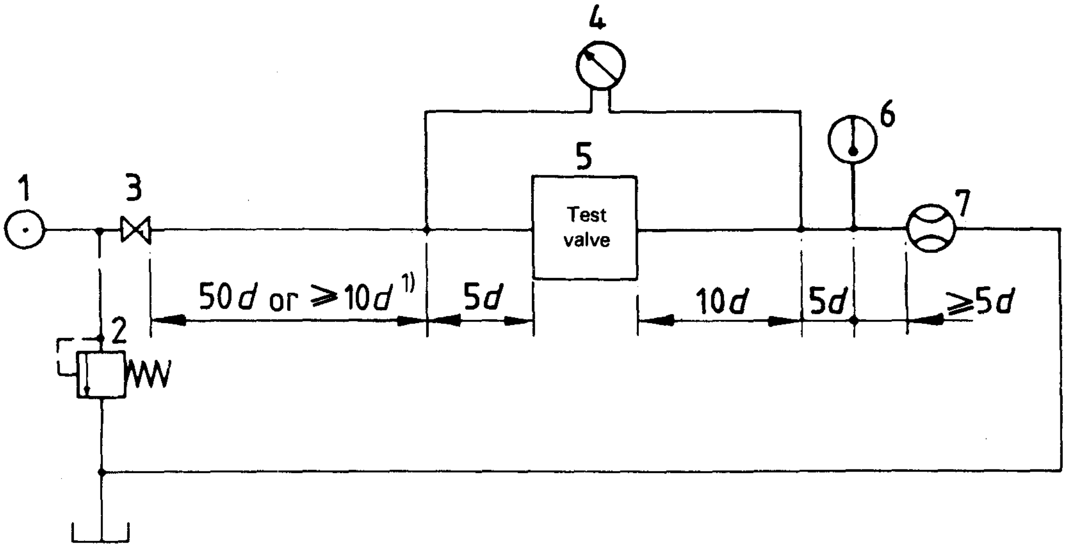
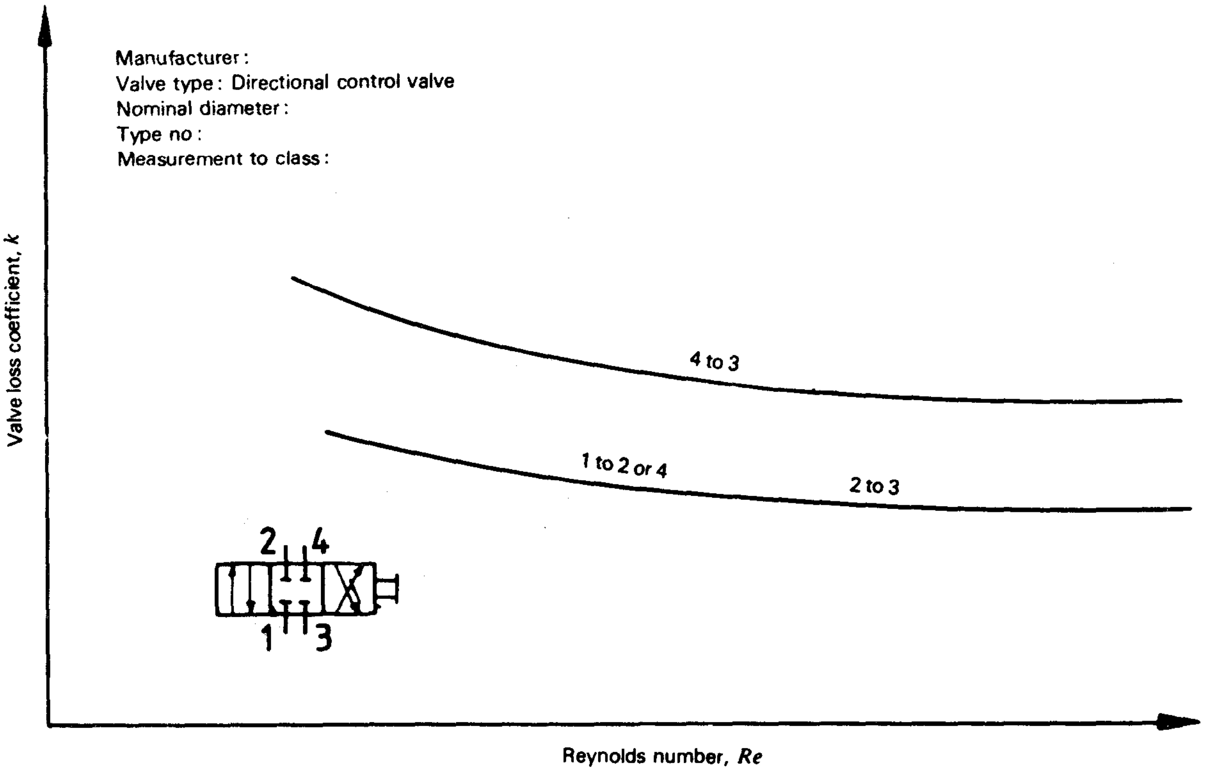
[1] The graphical results shown in figures 2 to 4 are shown for style of presentation only; no specific or related values are intended.



1 Controllable flow supply
2 Relief valve (circuit protection)
3 Stop valve (normally fully open)
4 Pressure differential measuring device
5 Test valve
6 Temperature at outlet of valve
7 Flowmeter

Figure 1 — Test circuit diagram



Manufacturer:
Valve type: Directional control valve
Nominal diameter:
Type no:
Measurement to class:

Figure 2 — Non-dimensional presentation of directional control valve

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[1] 50d for class A measurement accuracy; ≥ 10d for classes B and C measurement accuracy.

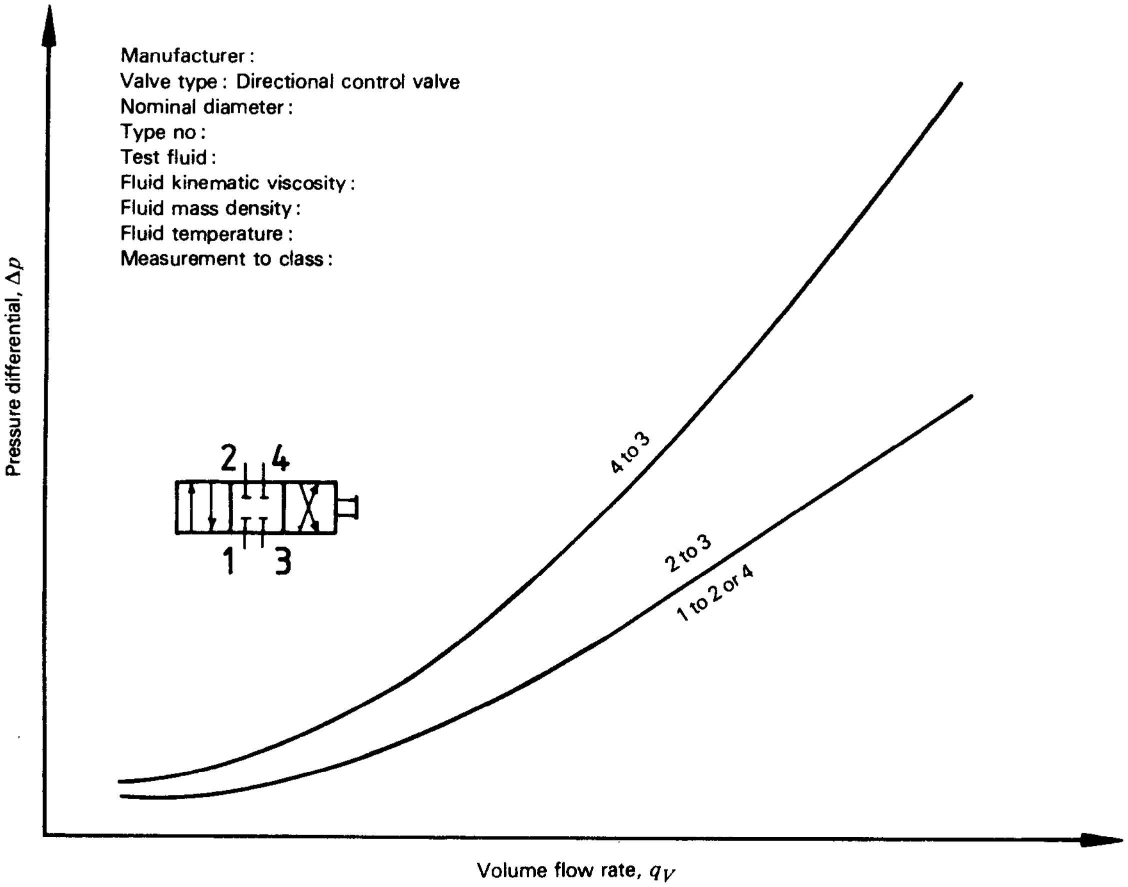

Figure 3 — Dimensional presentation of directional control valve

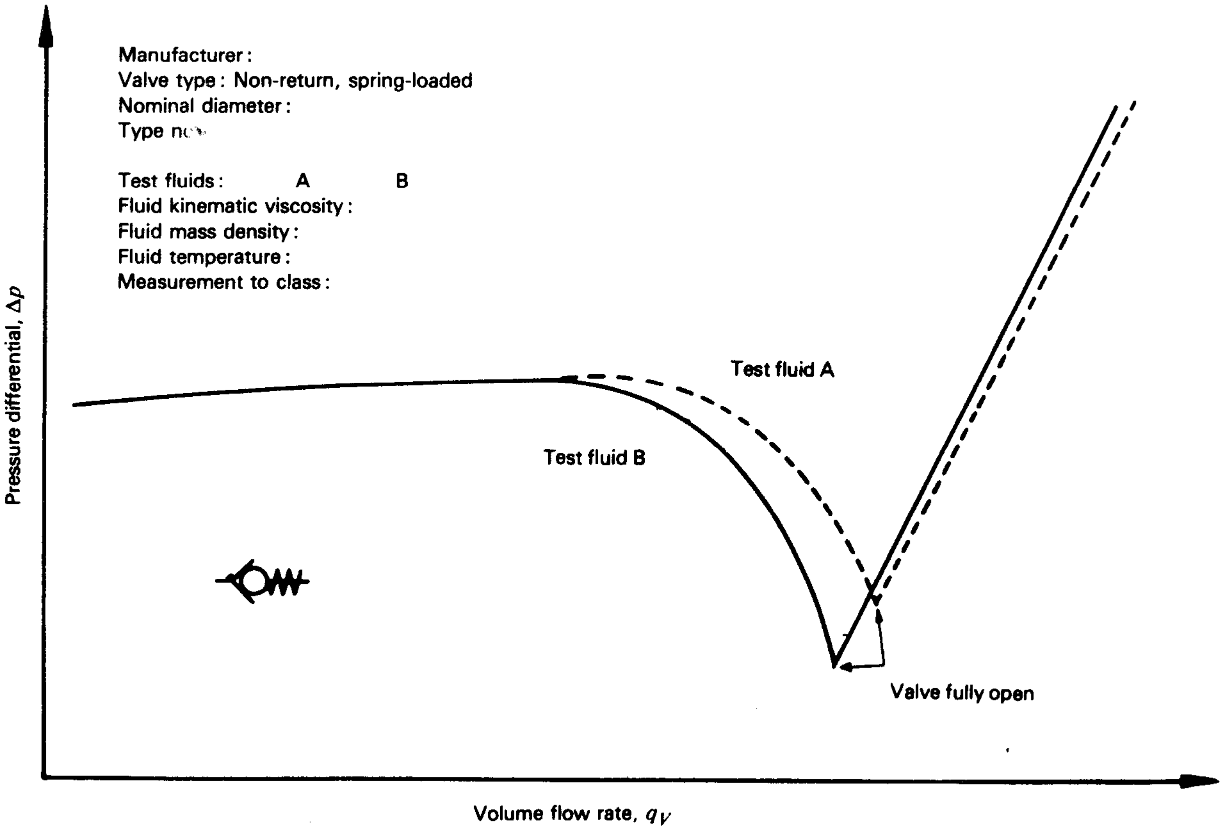

Figure 4 — Dimensional presentation of a non-return valve

Annex A

Errors and classes of measurement accuracy

NOTE — The contents of this annex are under review and may be subject to amendment in the future.

A.1 Classes of measurement accuracy

Depending on the accuracy required, the tests shall be carried out to one of three classes of measurement, A, B or C, as agreed between the parties concerned.

NOTES

1 Classes A and B are intended for special cases when there is a need to have the performance more precisely defined.

2 Attention is drawn to the fact that class A and B tests require more accurate apparatus and methods, which increase the costs of such tests.

A.2 Errors

Any device or method shall be used which, by calibration or comparison with International Standards, has been proven to be capable of measuring with systematic errors not exceeding the limits given in table 3.

NOTE — The percentage limits given in table 3 apply to the value of the quantity being measured and not to the maximum values of the test or the maximum reading of the instrument.

A.3 Combination of errors

When an end result is calculated from several measurements, the combination of errors involved in that result may be determined by the root mean square method.

Example (for loss coefficient, k):

$$k = \frac{2\Delta p}{\varrho u^2}$$

$$\frac{\delta k}{k} = \sqrt{\left(\frac{\delta p}{p}\right)^2 + \left(\frac{\delta \varrho}{\varrho}\right)^2 + 2^2\left(\frac{\delta u}{u}\right)^2}$$

The systematic errors used above, δp, $\delta \varrho$ and δu, are the actual systematic errors of the instruments and not the maximum values given in table 3. For more precise summation of errors refer to *Vocabulary of Legal Metrology — Fundamental Terms* published by the International Organization of Legal Metrology.

Table 3 — Permissible systematic errors of measuring instruments as determined during calibration

Parameter of measuring instrument	Permissible systematic errors for classes of measurement accuracy		
	A	B	C
Flow rate, %	± 0,5	± 1,5	± 2,5
Differential pressures, where $\Delta p < 2 \times 10^5$ Pa gauge, Pa[1]	± 2 × 10^3	± 6 × 10^3	± 10 × 10^3
Differential pressures, where $\Delta p > 2 \times 10^5$ Pa gauge, %	± 1,0	± 3,0	± 5,0
Temperature, K	± 0,5	± 1,0	± 2,0

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1) 1 Pa = 1 N/m²

Annex B

Pipe loss

B.1 As stated in 6.5, the valve pressure loss is obtained by subtracting the pipe loss from the total measured loss.

B.2 Using the D'Arcy formula, the préssure loss, Δp, for the test pipe can be expressed in any coherent set of units as

$$\Delta p = \mu \frac{l}{d} \frac{\varrho v^2}{2}$$

For the purposes of pipe loss calculations, the mean inside diameter of the pipe is measured to within 0,02 mm.

B.3 Figure 5 which shows the friction factor, μ, plotted to a base of the Reynolds number, Re, on log-log scales has been constructed for a value of μ, laminar flow, equal to $64/Re$. For turbulent flow, the value of μ, given by Blasius, of $0{,}316/Re^{0{,}25}$ has been used.

Reynolds number, Re, is, in this case, based upon the internal diameter of the pipe

$$Re = \frac{vd}{\nu}$$

B.4 For classes B and C measurement accuracy, the pipe loss may be determined by calculating Re, finding the value of μ from figure 5 and substituting this value together with the relevant values of l, ϱ, v and d in the formula given for Δp.

B.5 For class A, the μ-Re relationship is determined experimentally by removing the test valve and pipes from the installation shown in figure 1 and inserting a suitable length of identical pipe between the two pressure-tapping points. The length chosen should be such as to generate a pressure loss within the range of the available instrumentation at the minimum selected flow rate.

A curve similar to figure 5 may be constructed by substituting the test results obtained in the formula

$$\mu = \frac{2\Delta p d}{l \varrho v^2}$$

The pressure loss for the pipe lengths used in the valve test can be computed as described previously for classes B and C measurement accuracy but using the μ-Re curve which has been specially constructed.

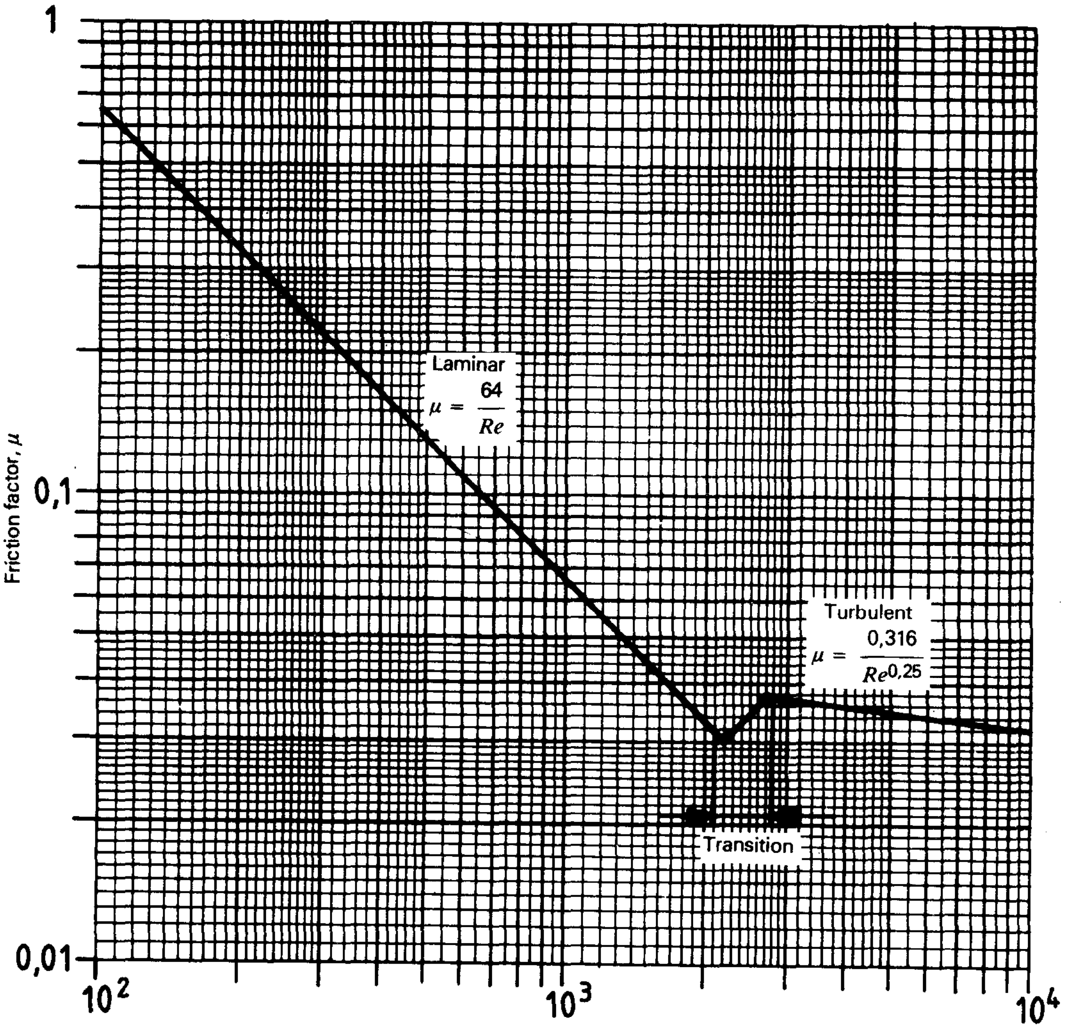

Figure 5 — Pipe friction factor

Annex C

Use of practical units

C.1 Practical units

The results of tests in either tabular or graphical form may be presented using practical units as given in table 4.

C.2 Calculations

In order to present results in practical units as given in table 4 and using volume flow rate rather than mean fluid velocity, the formulae given in this International Standard shall be modified as follows:

C.2.1 Reynolds number (see 3.5)

$$Re = 21{,}22 \frac{q_V}{\nu D} \times 10^3 \text{ (valve-related) and}$$

$$Re = 21{,}22 \frac{q_V}{\nu d} \times 10^3 \text{ (pipe-related)}$$

C.2.2 Loss coefficient (see 3.7)

$$k = 444 \frac{\Delta p \, D^4}{\varrho q_V^2} \times 10^{-3}$$

C.2.3 Pressure differential — valve (see 6.5)

$$\Delta p = \frac{k \varrho q_V^2}{444 \, D^4} \times 10^3$$

C.2.4 Pressure differential — pipe (see annex B)

$$\Delta p = \frac{\mu l \varrho q_V^2}{444 \, d^5} \times 10^6$$

C.2.5 Pipe friction factor (see annex B)

$$\mu = \frac{444 \, d^5 \Delta p}{l \varrho q_V^2} \times 10^{-6}$$

Table 4 — Practical units

Quantity	Symbol	Practical unit
Nominal diameter of valve	D	mm
Volume flow rate	q_V	l/min
Pressure differential	Δp	bar
Pipe length	l	m
Inside diameter of pipe	d	mm
Temperature	θ	°C
Kinematic viscosity	ν	mm^2/s (cSt)
Mass density	ϱ	kg/l

Annex D

Pre-test checklist

The following list constitutes a checklist for the selection of appropriate items upon which agreement is recommended between the parties concerned prior to testing[1]:

a) manufacturer's name;

b) manufacturer's identification (type No., serial No.);

c) manufacturer's description of valve;

d) nominal diameter of valve;

e) test circuit (see 5.1.1);

f) inside diameter of pipe (see 5.1.9 and annex B);

g) pressure-tapping positions (see 5.1.4);

h) pressure-tapping points (see 5.2);

i) filtration equipment used in test (see 5.3);

j) test fluid (by name and description) (see 6.1.1);

k) test fluid kinematic viscosity at test temperature (see 6.1.2 and 6.1.4);

l) test fluid mass density at test temperature (see 6.1.2 and 6.1.4);

m) test fluid temperature during test (see 6.2);

n) range of flow for test (see 6.4);

o) presentation of test results (see 6.7 and annex C);

p) class of measurement accuracy (see annex A);

q) determination of pipe loss (see annex B).

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[1] It will not always be necessary to agree upon all these items.

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